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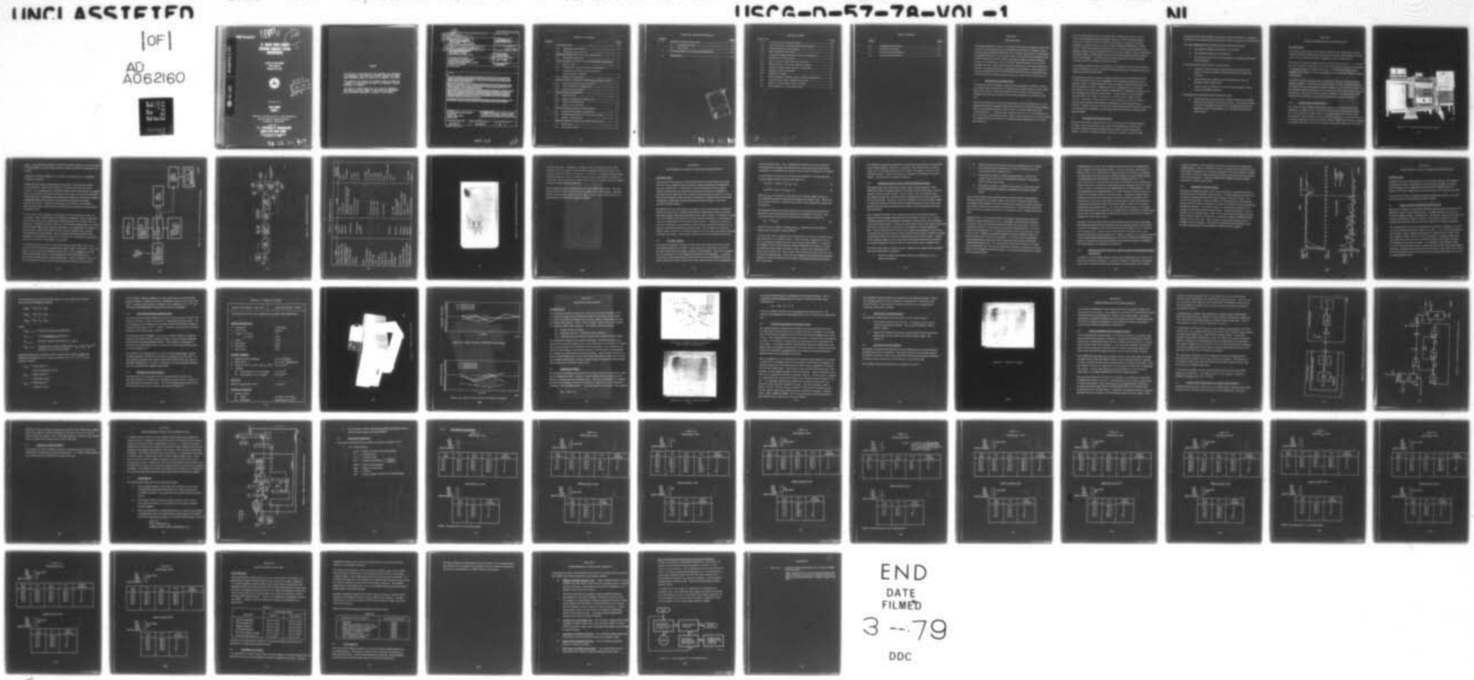

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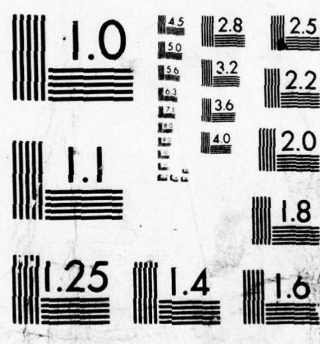
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REPORT NO. CG-D-57-78

LEVEL II

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ST. MARYS RIVER LORAN-C PRECISION GUIDANCE SYSTEM IMPROVEMENTS

TELEDYNE SYSTEMS COMPANY
19601 Nordhoff St.
Northridge, Calif. 91324

SEPTEMBER 1978

FINAL REPORT
VOLUME I

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16. Abstract

THIS REPORT PRESENTS THE MODIFICATIONS THAT WERE IMPLEMENTED INTO THE ST. MARYS RIVER LORAN-C PRECISION GUIDANCE SYSTEM TO IMPROVE NAVIGATION ACCURACY, GRAPHICS DISPLAY PRESENTATION, AND SYSTEM PERFORMANCE. IN ADDITION, THE DEGREE OF IMPROVEMENTS UNDER SIMULATED CONDITIONS ARE SHOWN.

PRIOR TO THE IMPLEMENTATION OF THE SYSTEM IMPROVEMENTS, THE UNITED STATES COAST GUARD TESTED AND EVALUATED THE LORAN GUIDANCE SYSTEM EXTENSIVELY ON USCG VESSELS AND A COMMERCIAL IRON ORE CARRIER. DURING THE TESTS SEVERAL DEFICIENCIES WERE OBSERVED IN THE SYSTEM'S ACCURACY AND GRAPHICS PERFORMANCE.

THE NAVIGATION ACCURACY OBJECTIVE IS A MAXIMUM CROSS-TRACK ERROR ON THE ORDER OF 25 FEET USING LORAN-C DATA INTEGRATED WITH GYROCOMPASS HEADING INFORMATION. TO ACHIEVE THIS OBJECTIVE THE PRECISION GUIDANCE SYSTEM HAS BEEN IMPROVED BY INCORPORATING A MORE ACCURATE LORAN RECEIVER OSCILLATOR AND MODIFYING THE KALMAN FILTER AND GYROCOMPASS SOFTWARE ALGORITHMS. IN ADDITION, THE RATE OF PROCESSING NAVIGATION DATA HAS BEEN INCREASED BY IMPROVING THE OVERALL SOFTWARE.

GRAPHICS DISPLAY PRESENTATION WAS IMPROVED BY MODIFYING THE SOFTWARE TO REDUCE CLUTTER ON THE DISPLAY SCREEN. SEVERAL PERFORMANCE IMPROVEMENTS WERE ALSO INCORPORATED.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

SECTION 1

INTRODUCTION

The implementation of Loran-C as the primary precision navigation system that meets the requirements of the United States Coast Guard for guiding a large vessel through restricted waterways such as the St. Marys River is undergoing a feasibility study by the U.S. Coast Guard. The results of the feasibility tests to-date indicate that Loran-C looks promising for high-precision navigation. However, the shipboard Loran-C Precision Guidance System which has been funded by the U.S. Coast Guard required modifications to improve navigational accuracy, system performance, and graphics presentations. This report describes in detail those factory modifications that have been incorporated in the Loran-C Precision Guidance System and the test results of the improvements.

1.1 BACKGROUND INFORMATION

A shipboard precision guidance system has been needed for a number of years by mariners that would aid them to safely traverse large vessels, such as Great Lakes ore carriers of 1000-foot length and 100-foot beam, through narrow channels such as in the St. Marys River where channels are as narrow as 300 feet.

The St. Marys River is a 65 mile waterway that connects Whitefish Bay in Lake Superior to DeTour Passage in Lake Huron and serves as the only water shipping route connecting Lake Superior with the rest of the Great Lakes and the St. Lawrence Seaway. Presently safe navigation in this river is accomplished with the aid of buoys, shore aids and ship's radar; unfortunately these conventional aids for navigation become ineffective or unusable during conditions of low visibility and winter ice.

Since the United States policy on marine radio navigation states that Loran-C will be the navigation system provided for the U. S. Coastal Confluence Zone (CCZ), the United States Coast Guard has undertaken a program to study the feasibility of using Loran-C as a prime aid in restricted waterways. In 1976 the U.S. Coast Guard funded the development of a computerized shipboard Loran guidance system and the establishment of a special four-station Loran-C Mini-chain at St. Marys River, which consists of two transmitting stations located in Canada and two in Michigan. A monitor station located at Sault Ste. Marie, Michigan remotely controls the stability of the transmitters.

The minimum distance from the waterway to a transmitter is seven miles, and the maximum distance is 60 miles thereby providing good signal coverage and geometry within the St. Marys River area.

The shipboard Loran-C Precision Guidance System was first installed in the fall of 1976 aboard the USCG Cutter Naugatuck, a 110-foot tug boat operating out of Sault Ste. Marie, Michigan and tests were performed to calibrate the system and check positional accuracy. Additional tests and evaluations were performed aboard other U.S. Coast Guard vessels to determine the feasibility of using Loran-C as a navigation aid on the St. Marys River. Further tests were performed in 1977 and 1978 on the Arthur M. Anderson, a 767-foot Great Lakes iron ore carrier. The system using Loran-C as a prime sensor has shown the ability to provide useful guidance information for navigating in restricted waterways. However, results of the tests, evaluations, and demonstrations conducted to that time revealed that the navigational accuracy and graphics performance required some improvements.

1.2 PURPOSE OF IMPROVEMENTS

During the field tests conducted by the U.S. Coast Guard and Teledyne Systems Company, several deficiencies were noted in the performance of the Loran Precision Guidance System that degraded the system accuracy and graphics display. Therefore Teledyne Systems Company was funded to conduct a study

program to analyze the problems and determine what modifications to hardware and software were required for improving the system's accuracy and performance.

The study highlighted several deficiencies that required correction.

a. The graphics display redraw speed was too slow.

b. The graphics display was too cluttered.

c. Too much computer time was being spent on compiling the graphics data for display.

Deficiencies that degraded system accuracy were:

a. Computed estimate of ship's speed based on the Kalman filter output of velocity components (east and north) were frequently incorrect.

b. Kalman filter gain control was not mechanized correctly for optimum system performance.

c. Loran receiver's oscillator was not accurate enough to achieve required repeatable accuracy.

One problem that degraded system performance was:

a. Loran status data received by the computer did not always agree with the actual status of the Loran receiver. This incorrect status prevents the navigation software from accepting and processing legitimate Loran-C time differences, and effectively stops the whole system.

SECTION 2

SYSTEM DESCRIPTION AND CONFIGURATION

INTRODUCTION

The purpose of this section is to briefly describe the St. Marys River Loran-C Precision Guidance System that is being used to evaluate the feasibility of using Loran-C for precision all-weather navigation on the St. Marys River.

The Loran-C Precision Guidance System (LPGS) shown in Figure 2-1, is a high-precision navigation system that uses Loran-C data and gyrocompass information for navigating ships in restricted waterways. In addition the system has the capability to be used as a research and development tool to study future navigation requirements.

The LPGS is a disc operating system controlled by Hewlett-Packard's DOS III software routines. A dual disc unit accommodates two IBM compatible diskettes with 128K (16 bit word) capacity per disk providing a total of 256,000 16-bit words. This provides sufficient storage for the operating program and for future program development. The majority of the computer programs were developed in FORTRAN IV which allows for rapid software checkout and program changes.

2.1 FUNCTIONAL DESCRIPTION

The LPGS provides navigation information relative to a predicted safe track through the St. Marys River. The system receives up to four Loran-C signals from the Loran-C Mini-chain (4930) and heading information from the ship's gyrocompass. These signals are processed by a Kalman filter algorithm to give a continual indication of off-track distance (lateral displacement from the intended track), time and distance to the next waypoint, along-track speed and cross-track

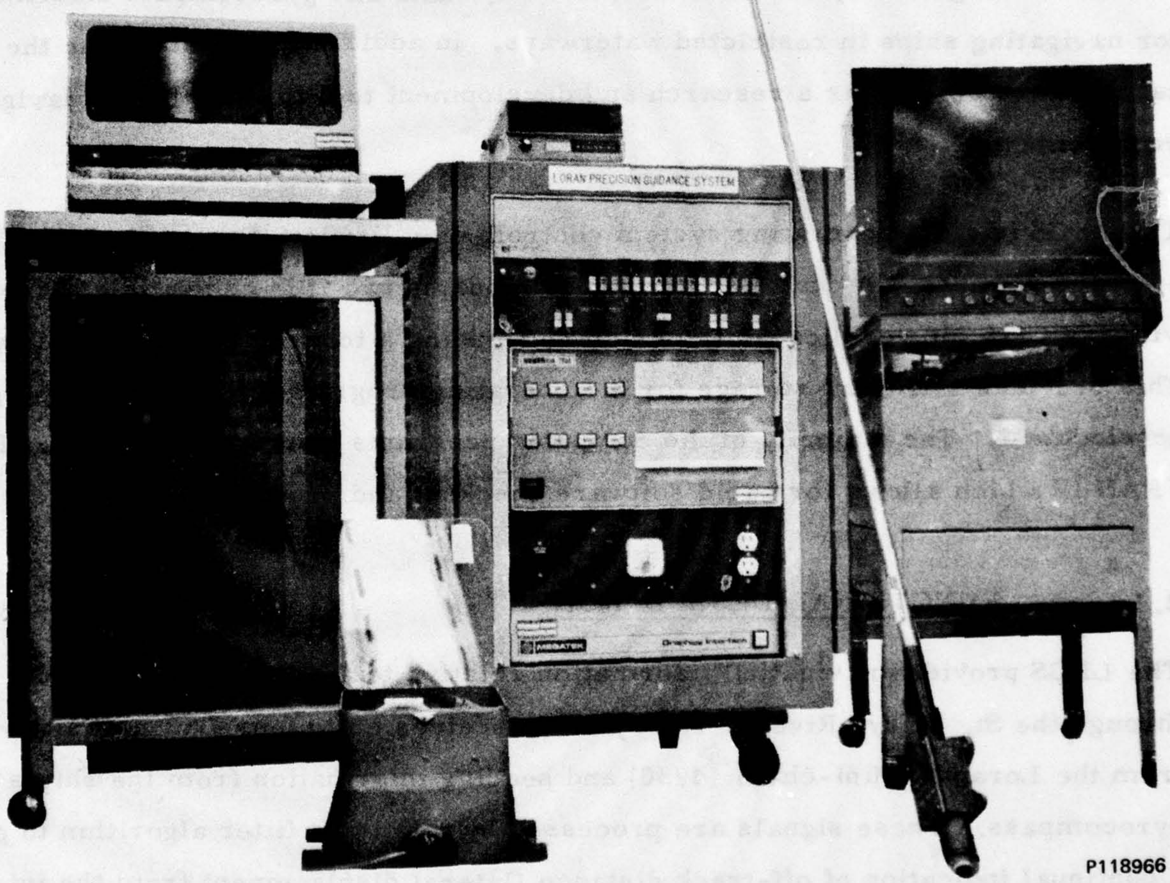

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Figure 2-1. Loran Precision Guidance System

speed. The system also provides a prestored pictorial display of the local area on a 17 inch cathode-ray tube (CRT) showing the ship's position and progress in the channel.

Figure 2-2 is a block diagram of the system, and Figure 2-3 is a simplified system flow diagram.

Present position (latitude and longitude) of the ship is calculated by optimal processing of the Loran-C time difference measurements from the Loran receiver. The measurements are gathered approximately three times per second (about every seventh GRI) and processed by a four state Kalman filter algorithm. The Kalman filter sequentially processes the time differences plus gyro-compass heading information and provides a smoothed best-estimate of the ship's position and velocity. Guidance information is calculated by comparing the ship's position with a prestored table of waypoints that defines the desired track through the river.

A 12 inch CRT on the operator's console unit (HP-2645) displays the date and time of day, ship's present position in latitude and longitude, course, speed over ground (miles per hour), gyrocompass heading (degrees true), time to the next turn (hours, minutes, seconds), distance to the next turn (statue miles), off-track distance (feet right or left of channel centerline), crab angle (degrees relative to desired track), cross track speed (feet per second), and the Loran receiver tracking status for each station. Figure 2-4 illustrates the navigational data displayed on the operator's console unit, and Table 2-1 indicates the parameters which can be entered or displayed on the console.

A graphics display unit with a 17 inch CRT presents a geographic image of the St. Marys River including an outline of the channel edges, centerlines, buoys, and lights. Also a scaled representation of the user's vessel is displayed showing position and attitude relative to the channels as derived from the Loran-C measured time differences and gyrocompass data. Refer to Section 5, Figure 5-1 for an illustration of the St. Marys River and vessel symbol on the screen as

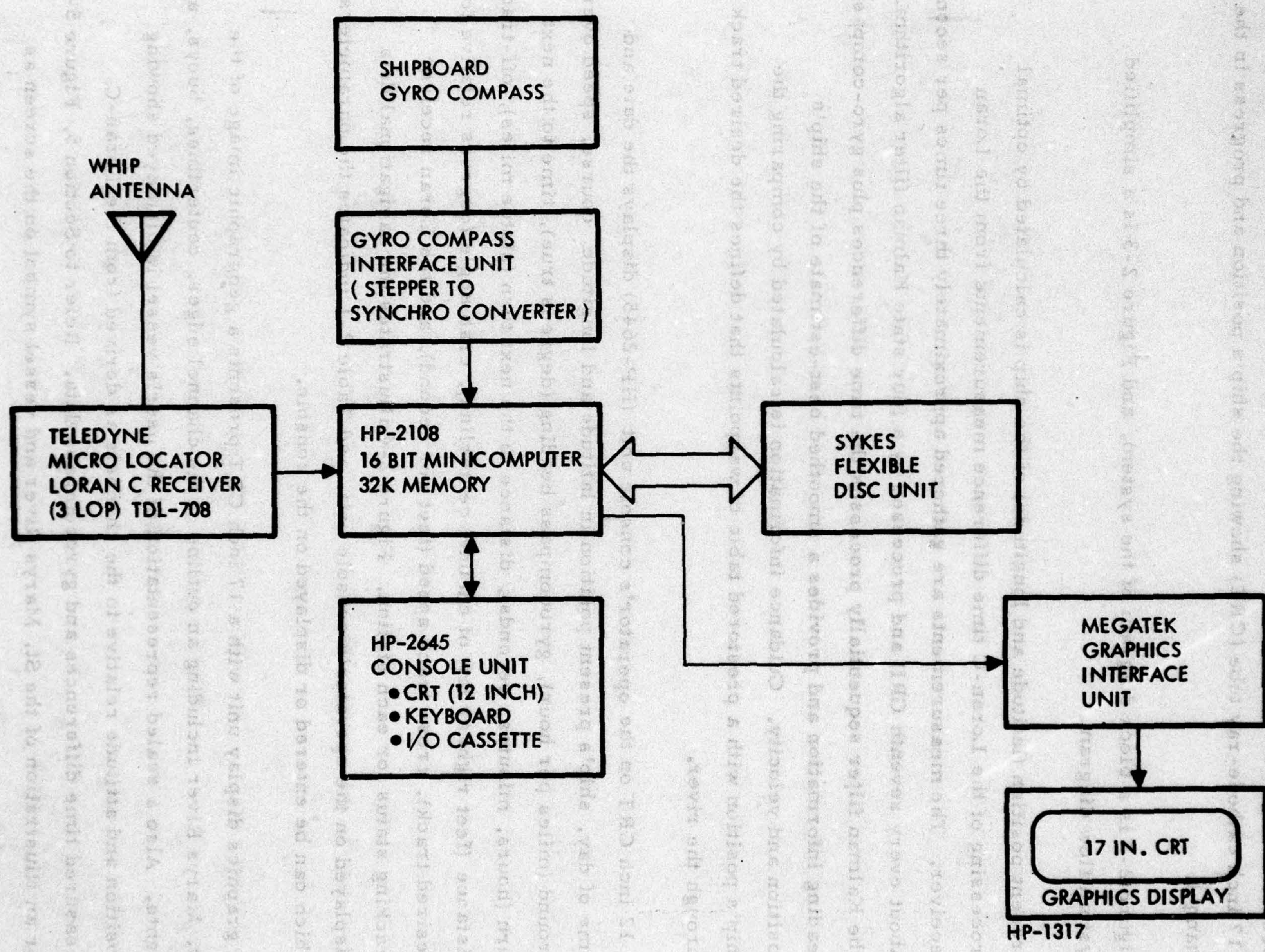


Figure 2-2. Loran Precision Guidance System Block Diagram

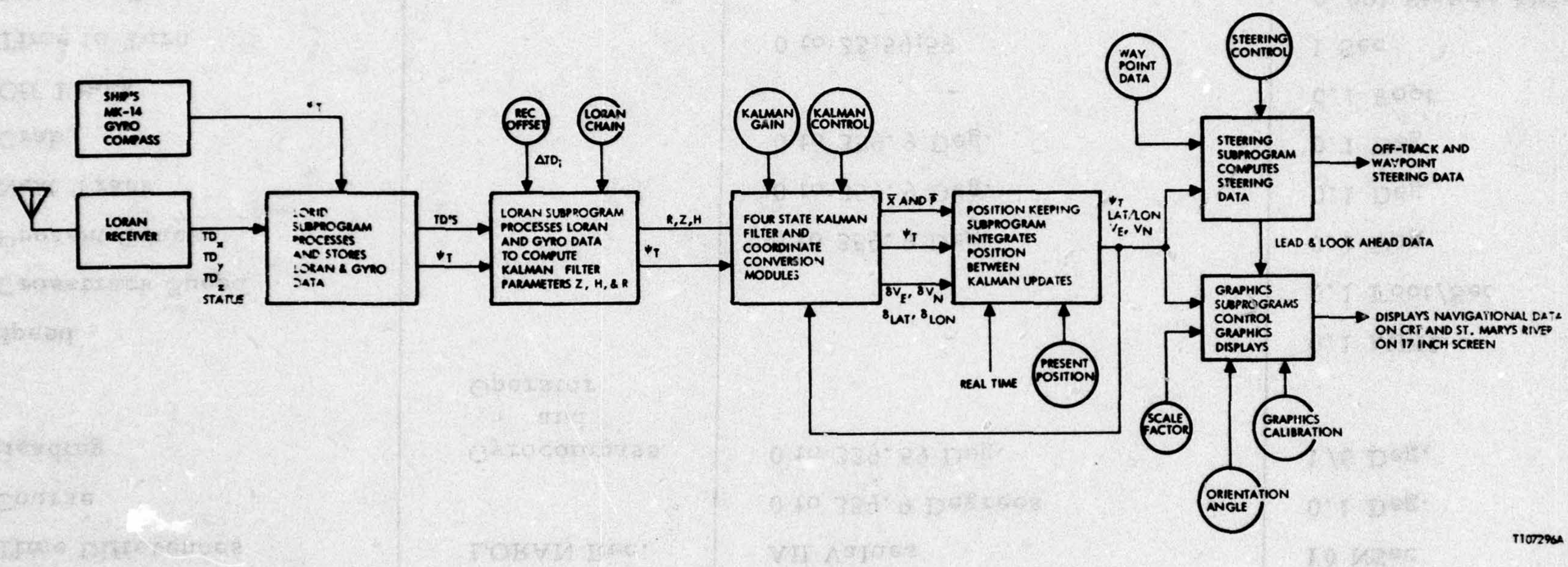


Figure 2-3. Simplified System Flow Diagram

Table 2-1. Navigational Parameters

Data	Input	Range	Displayed Resolution
Julian Calendar Day	Operator	1 to 366	1 Day
Greenwich Mean Time	Operator	0 to 23:59:59	1 Sec
Present Position: L/L Latitude/Longitude	Operator	-89,59.999 to +89,59.999 Deg. -180,0.0 to 179,59.999 Deg.	.001 Minute
Time Differences	LORAN Rec.	All Values	10 NSec
Course		0 to 359.9 Degrees	0.1 Deg.
Heading	Gyrocompass and Operator	0 to 359.59 Deg.	1/6 Deg.
Speed		-	0.1 MPH
Crosstrack Speed			0.1 Foot/Sec
Present Track		0 to 359.9 Deg.	0.1 Deg
Next Track		0 to 359.9 Deg.	0.1 Deg
Crab		0 to 359.9 Deg.	0.1 Deg
Off Track		-	0.1 Foot
Time to Turn		0 to 23:59:59	1 Sec
Miles to Turn		-	0.001 Statute Mile
Lead	Operator	-	1 Foot
Quality Factor		0 to 100%	N/A
Waypoint	Operator	Up to 35 waypoints can be entered	-
Look-Ahead	Operator	Entry in time or distance	-
Receiver TD Offset	Operator	1 Nsec - 1 millisecond	+
Graphics Position Offset	Operator	1 degree L/L	.001 Minute
Graphics Scale Factor	Operator	1 to 20 inches/mile	Integer

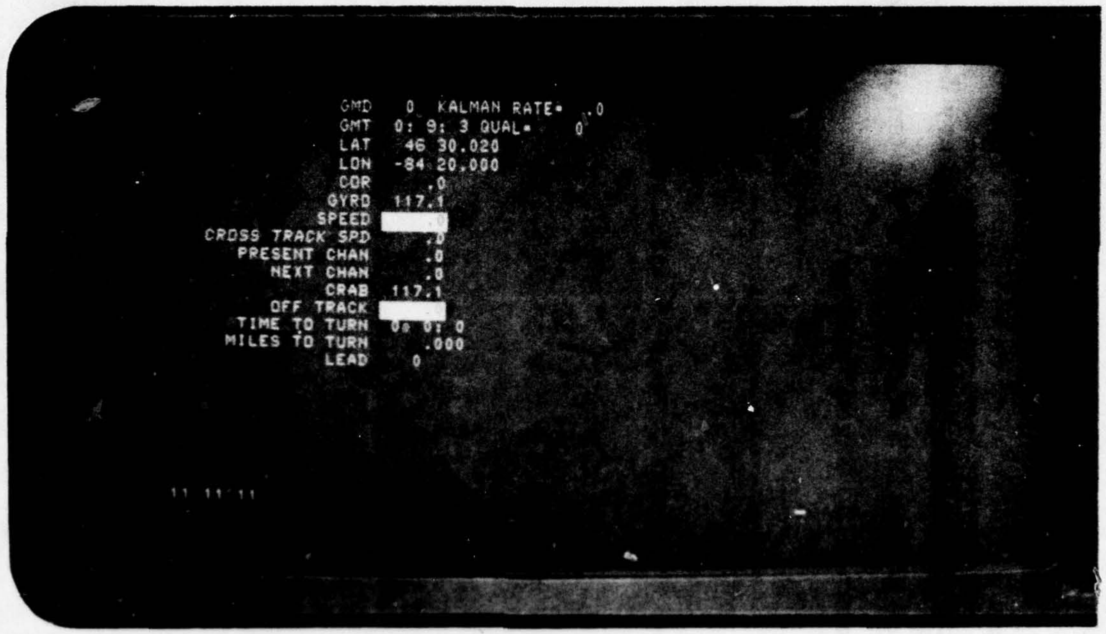


Figure 2-4. Data Displayed on HP-2644 Operator's Console

viewed by the user. In addition, a heading vector emanating from the vessel symbol projects an operator-selected time or distance ahead of the ship. The operator can select either a "North-up" or "Track-up" orientation and can change scale to show from 1/20 to one mile per inch on a ten-inch square viewing area of the CRT, which has a green contrast filter with an anti-glare surface to enhance viewing in bright daylight conditions.

Also navigational data are displayed on the upper right of the screen. This data and the position of the vessel symbol is updated every 2-1/2 seconds. When the vessel image reaches within 15% of the edge of the ten-inch viewing square, the next portion of the channel is paged for display.

SECTION 3

NAVIGATIONAL ACCURACY SOFTWARE IMPROVEMENTS

INTRODUCTION

The purpose of this section is to describe the improvements which were made to the St. Marys software with the specific intent of enhancing the navigational accuracy performance. In particular certain modifications to the graphics software package take less time and make somewhat more time available for the Kalman processing with some collateral improvement in navigation accuracy. These improvements, while welcome, are difficult to quantify and are the result of software modifications described elsewhere in this report so will not be considered in this section.

Specifically, the two broad task areas singled out for improvement of navigation system accuracy were: (1) filter tuning and (2) modification of the gyrocompass data processing to enhance the estimates of the ship's velocity. In addition, certain simulation studies were performed to determine the desirability of modifying the receiver's mechanization of the master phase tracker. Aside from the specific area just mentioned, certain portions of the routines LORAN and SYSUP were re-coded to eliminate unnecessary multiplications. This recoding increased the Kalman update rate with a resultant increase in accuracy due to the higher frequency of Kalman processing. These improvements will now be discussed individually.

3.1 FILTER TUNING

In the system operation, the time between successive calls to the Kalman filter processing algorithm is variable. It can range from a fraction of a second to several seconds when the graphics display is being updated. This time variability was not accounted for in the original construction of the algorithm. A constant value of the system disturbance Q matrix was used in the calculation of the updated predicted covariance matrix once every Kalman update cycle independently of

the time between calls. This resulted in the addition of incorrect variance components due to random state disturbance so that when these effects were propagated via the Kalman gain matrix, incorrect filter weights were calculated.

If a discrete time version of the system state equations are written then the velocity update equations have the following form.

$$V_E(n+1) = V_E(n) + A_E(t_{n+1} - t_n) \tag{1}$$

$$V_N(n+1) = V_N(n) + A_N(t_{n+1} - t_n) \tag{2}$$

where t_n, t_{n+1} are the times of the (n) and (n+1) system update and A_E, A_N are random accelerations experienced during the nth update cycle. This is the discrete time version of continuous time linear motion disturbed by white noise acceleration.

The purpose of the Q_V or velocity Q terms is to account for the mean square disturbance due to the random forcing terms in equations (1) and (2). Thus from (1) and (2) we see that the Q velocity terms should be of the form:

$$Q_v = \sigma^2 \Delta t_{n+1}^2 \tag{3}$$

where σ^2 is some positive constant and Δt_{n+1} represents the time interval between the (n) and (n+1) system updates.

The subroutine which computes the predicted state covariance matrix which uses these quantities is the SYSUP routine. SYSUP has been recoded so that the Q terms now properly depend upon the time between system updates. In addition, the original version of this program utilized FORTRAN "DO" loops to compute the predicted system state covariance matrix. Many of the multiplications in these loops involved one or more factors which were always zero, which is very wasteful of computer time. This code was replaced by mathematically equivalent statements which economized on the number of multiplication operations which were performed.

It is difficult to quantitatively specify the improvements gained from modification of the SYSUP program. However, comparative runs indicate that the Kalman update rate is somewhat higher and that velocity convergence is better for the modified program. Refer to Volume II for listings of the modified versions of SYSUP. The new code is explicitly indicated.

3.2 MODIFICATION OF GYRO COMPASS MECHANIZATION

Operational data from field tests on the St. Marys system indicated certain deficiencies in the computed estimate of the ship's speed based upon the Kalman outputs of east and north velocity. First, during a turn the computed speed was highly variable and in particular gave readings that were only a fraction of the true ship speed. Moreover, after the completion of a turn, the filter tended to retain the memory of the false speed computed during the turn so that a time lag was introduced into the post-turn convergence of the computed speed to the true ship speed.

Gyro compass information was originally processed by the Kalman filter as though what was actually being measured was the ship's course, i.e., arctan (VE/VN), instead of the directional orientation of the body axis of the ship which is the actual measurement. This is incorrect if there is any crab angle in the motion so that the velocity vector of the ship is not aligned to the ships longitudinal axis. Another possible error source in the original mechanization is that errors associated with the MK-14 gyro compass could be biased and/or strongly correlated so that they would not be reduced by passage through the Kalman filter. Finally, in the original program, no use was made of the heading information furnished by the gyro compass to directly rotate the ship velocity vector through a turn.

To improve the quality of system velocity estimates, four experimental modifications were proposed for evaluation:

1. Use gyro compass information only for turn detection, not as a Kalman observable.

2. Retain the original algorithm during the straight track run. Modify the turn logic and use differential heading to rotationally aid the ship velocity vector through a turn.

3. Retain gyro heading as a Kalman measurement. Null out turn detection logic and always use differential heading to rotationally aid the ship velocity vector.

4. Drop gyro compass as a Kalman measurement, remove turn logic and use differential heading to rotationally aid the ship velocity vector.

Each of these options was investigated and/or experimentally implemented. Analysis showed that if the gyro compass data was of such poor quality that it was unfit for both rotational velocity aiding and processing as a Kalman measurement then it would also be unsuitable as the basis for a turn detection algorithm. Hence (1) was not programmed since its unsuitability could be determined before hand.

Modification No. 2 was implemented by utilizing the waypoint arrival logic in STEER to flag the initiation of a turn. Knowledge of the waypoints permitted calculation of the total heading change associated with a given turn. This permitted the inclusion of logic which set flags which indicated whether or not the vessel was negotiating a turn. Rotational aiding was only used when the vessel was in a turn. POSKP was modified slightly so that the rotational aiding was activated only when a turn was in progress. The results of this modification were disappointing in that the computed estimate of ship speed still dropped significantly during a turn. The turn detection logic did not seem to do a good job of identifying turns. Since this modification offered no performance improvement over the original unmodified program, it was discarded and does not appear in the improved system.

Modifications No. 3 and 4 were implemented simultaneously by making fairly minor changes to the subroutine POSKP. In the new baseline configuration, if sense switch 7 is on, then the gyro compass reading is used both as an input to the Kalman filter as well as for the rotational aiding of the ship velocity vector, corresponding to the mechanization specified in Modification No. 3. If sense switch seven is off then the gyro compass information is not passed to the Kalman filter but is only used to rotationally aid the updating of the ship velocity vector, which is compatible with the Modification No. 4 implementation. This dual implementation of Modifications No. 3 and 4 and their control by means of a sense switch makes sense for several reasons. If the gyro compass data is relatively error free and if the random errors are weakly correlated in time and if there is little or no crab angle in the ship motion, then the gyro data can profitably be used both as input to the Kalman filter as well as for rotational aiding of the ship velocity vector. If, on the other hand, there is a crab angle in the ship motion or if a large bias or strongly time correlated error contaminates the gyro data, then differential heading data will still be useful for the rotational aiding of the ship velocity vector.

Extensive runs have shown that with both modifications (3) and (4) implemented that significant improvement is obtained over the original version of the program in terms of convergence of the computed speed and the behavior of the computed speed during a turn. These runs also indicate that cross track error is not adversely affected by these modifications. Shown in Figure 3-1 is a typical response of the system under simulated navigation runs with and without the modifications. Refer to Volume II for the source listings of the modified versions of POSKP for the implementation of modifications (3) and (4).

3.3 MISCELLANEOUS CLEAN-UP AND INCLUSION OF REVERSE MOTION CAPABILITY

In addition to the preceding changes certain other modifications were made to the Kalman processing subroutines. A portion of CORCN, in particular the updating of the state covariance matrix after processing a measurement, was rewritten

to ensure symmetry of the resultant matrix and to eliminate any unnecessary multiplications. Also, an addition was made to LORAN which permits the use of gyrocompass information as a Kalman measurable even when the ship is backing (ship velocity vector is approximately 180 degrees out of phase with the reading from the gyrocompass). Volume II contains the modified versions of these subroutines, CORCN, and LORAN.

3.4 DEGREE OF IMPROVEMENT

Numerous simulated navigation runs were performed to evaluate the system's performance with and without improvements. A LORAN Dynamic Test Set which is capable of simulating any profile under computer control was used. The profile used simulated a vessel traveling from Whitefish Bay in Lake Superior towards Sault Ste. Marie, Michigan at a speed of 14 miles per hour and navigating through one waypoint. As shown in Figure 3-1, the dynamic response of the system is much better with the improvements. Before modification, it took 2.5 minutes for the indicated speed to grow to the actual simulated speed of 14 mph. When turning through the waypoint (at a simulated 14 mph), the indicated speed dropped as low as 8.5 mph. After modification the indicated speed grew to 14 mph in only 0.5 minutes. In the turn, the indicated speed dropped to only 11 mph, and rose back to the simulated 14 mph much more quickly.

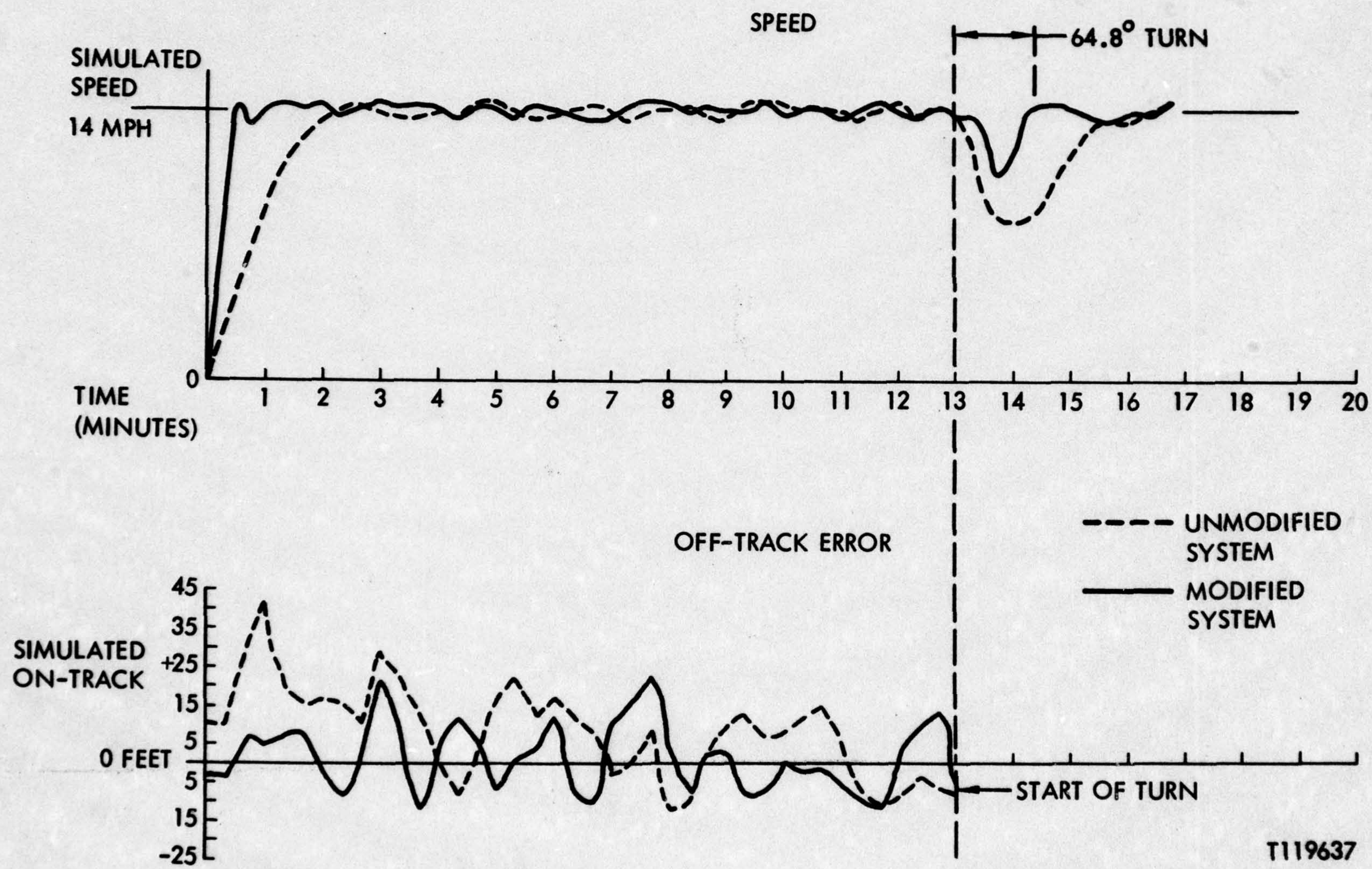


Figure 3-1. Response of System (Modified Versus Unmodified)

SECTION 4

NAVIGATIONAL ACCURACY HARDWARE MODIFICATION

INTRODUCTION

Although most of the improvements were done in the software, one hardware modification was also implemented to further improve navigation accuracy. The modification was implemented in the TDL-708 LORAN receiver to improve LORAN time difference accuracy by using a more accurate oscillator.

This section describes in detail the hardware modification made to the LPGS system to improve accuracy along with test results.

4.1 MORE ACCURATE RECEIVER OSCILLATOR

Basically the system accuracy starts with the mean and standard deviation time difference errors of the LORAN receiver. Standard deviation errors are a function of signal strength, external noise, and internal receiver noise which are variable and harder to control. However, the mean time difference errors (biases) of the receiver can be reduced by using a more accurate oscillator. The original TDL-708 receiver oscillator has a frequency stability of $\pm 1 \times 10^{-6}$ over the operating temperature range of 0° to 60°C. It is a TCXO (temperature compensated crystal oscillator) operating at a frequency of 12.8 MHz. When this oscillator drifts near the limit of its tolerance, a relatively significant time difference (TD) mean error results since mean error offset is directly proportional to the frequency change. For example, if the oscillator drifts $\pm 1 \times 10^{-6}$ when operating in the St. Marys River area with Z secondary station, which has a coding delay of 32999.988 microseconds, a mean TDZ error of more than 30 nanoseconds would be induced into the system which equates to an error of approximately 30 feet.

The time differences measured by the LORAN receiver within the St. Marys River area can be defined as follows:

$$\Delta t_{MX} = \Delta t_X + D_X + R_{BX}$$

$$\Delta t_{MY} = \Delta t_Y + D_Y + R_{BY}$$

$$\Delta t_{MZ} = \Delta t_Z + D_Z + R_{BZ}$$

where,

$\Delta t_{MX, Y, Z}$ - Measured receiver time difference

$\Delta t_{X, Y, Z}$ - True propagation-time difference

$D_{X, Y, Z}$ - Absolute, delay for secondary X, Y, and Z

$R_{BX, Y, Z}$ - Receiver bias (oscillator offset) where $R_{BX} = (\Delta t_X + D_X)\,10^{-6}$ (oscillator error in parts/million)

Using time differences measured at the St. Marys River monitor station, the following time difference errors with an oscillator error of $+1 \times 10^{-6}$ can be equated as follows:

$$R_{BX} = (11259.349)\,10^{-6}$$
$$= .0112 \text{ microseconds} \approx 10 \text{ ft}$$

$$R_{BY} = (22365.998)\,10^{-6}$$
$$= .0223\ \mu\text{sec} \approx 20 \text{ ft}$$

$$R_{BZ} = (33185.805)\,10^{-6}$$
$$= .033\ \mu\text{sec} \approx 30 \text{ ft}$$

As was shown, oscillator stability is a factor that must be considered when trying to achieve a positional accuracy repeatability within 25 feet, 95% of the time. By using a more accurate oscillator with a stability of $\pm 1 \times 10^{-7}$, the TD errors can conceivably be reduced by an order of magnitude.

4.2 TDL-708 RECEIVER MODIFICATION

A more accurate and stable oscillator has been incorporated into the TDL-708 receiver, SN-0112, to reduce TD biases by replacing the existing TCXO. The new oscillator is a 12.8 MHz oven controlled crystal unit that has a frequency stability of better than 1×10^{-7}. Table 4-1 shows the test data of the oscillator installed in TDL-708 receiver, SN-0112.

Due to the size of the oscillator, 4 x 1.4 x 1.3 inches, it had to be mounted outside of the receiver since a smaller oscillator wasn't available within the time-frame of the improvements contract. The oscillator is mounted in a 2.25 x 2.25 x 5 inch chassis which is secured to the top cover of the receiver as shown in Figure 4-1.

The oscillator oven operates from 115 VAC @ 300 MA steady state, and the oscillator requires + 12VDC @ 21 MA which is supplied by the TDL-708. An oven indicator mounted in the chassis illuminates when the oven has reached operating temperatures. In order to maintain the required frequency stability, the oven must have power applied continuously.

4.3 DEGREE OF IMPROVEMENT

Six static tests were performed with the original oscillator and the oven controlled oscillator to determine the magnitude of improvement. Figure 4-2 shows graphically the improvement. The most noticeable improvement is the TD mean error from turn-on to turn-on as shown in Figure 4-3.

Table 4-1. Oscillator Test Data

Ovenaire Part Number: OSC 22-23	Unit Serial Number: 27317-1

The following test data were measured in accordance with specification.

Output Characteristics

1.	Frequency:	12.800 MHz
2.	Wave Form:	Sq Wave
3.	Output: "0" Level	.2V
	"1" Level	4.0V
4.	Load:	5 TTL
5.	Rise Time:	8 NS
6.	Fall Time:	4 NS
7.	Duty Cycle:	56%

Frequency Stability

1.	Aging (at time of shipping)	$<1.0 \times 10^{-9}$ /week
2.	Short Term:	$<4.0 \times 10^{-10}$ RMS/10 Sec
3.	Ambient: $-20^{\circ}C$ to $+70^{\circ}C$ Ref. to $+25^{\circ}C$	$<\pm 1.0 \times 10^{-8}$
4.	Voltage:	
	(a) $\pm10\%$ change in 117 VAC supply	$<1.0 \times 10^{-9}$
	(b) $\pm5\%$ change in +12.0V supply	$<2.7 \times 10^{-9}$

Warm-Up

After 15 minutes from $-20^{\circ}C$	1.0×10^{-7}

Frequency Adjustment

1.	Coarse Control:	
	(a) Range	+5.6 ppm, -10.1 ppm
	(b) Resolution	Better than $\pm 5.0 \times 10^{-9}$

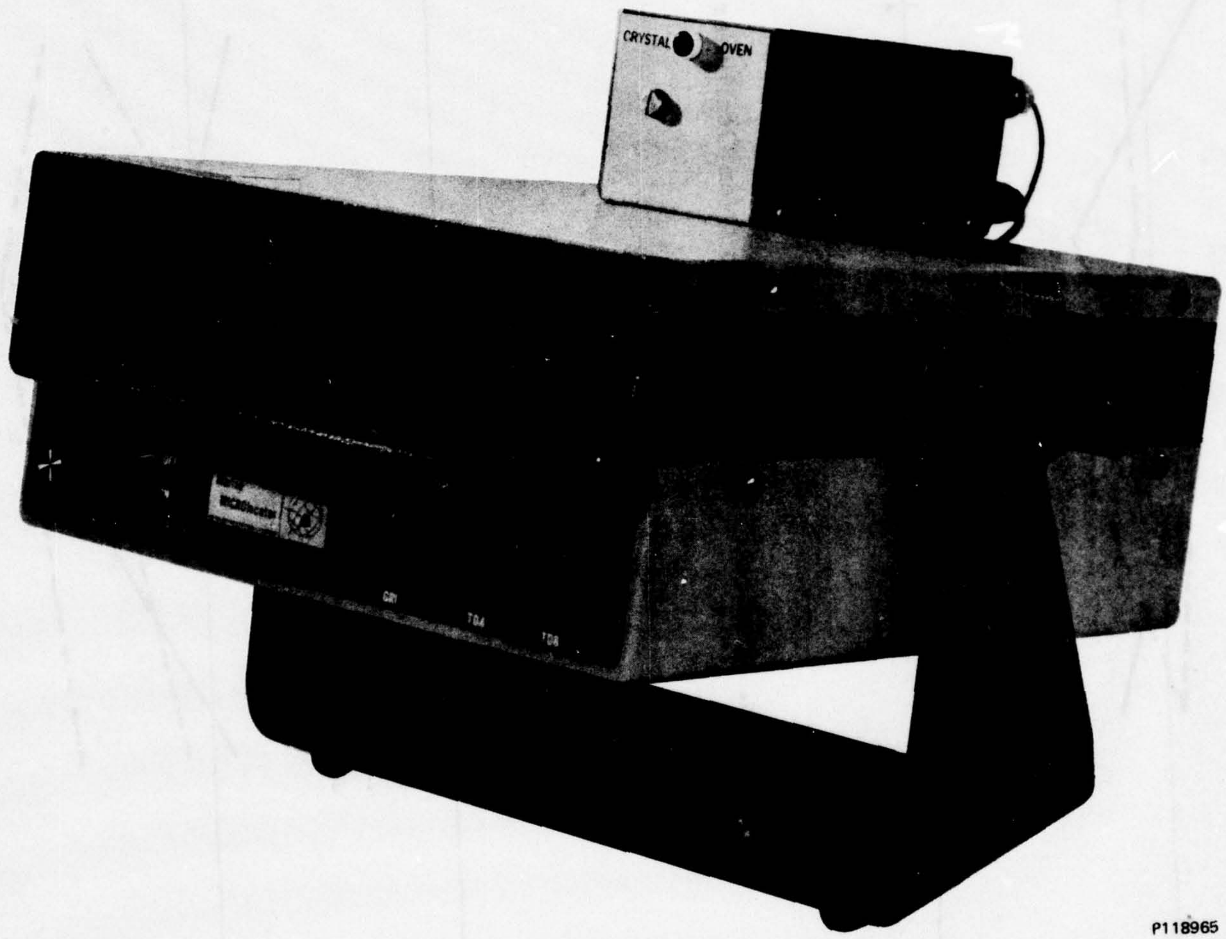


Figure 4-1. Modified TDL-708 Receiver

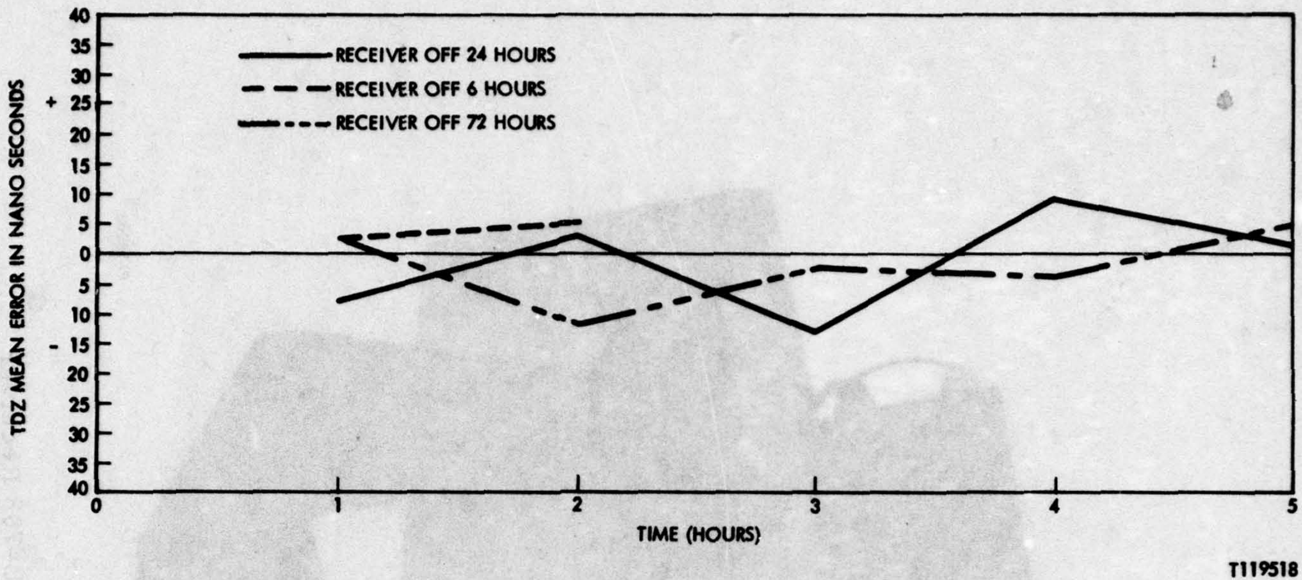


Figure 4-2. Static Accuracy Tests With Oven Oscillator

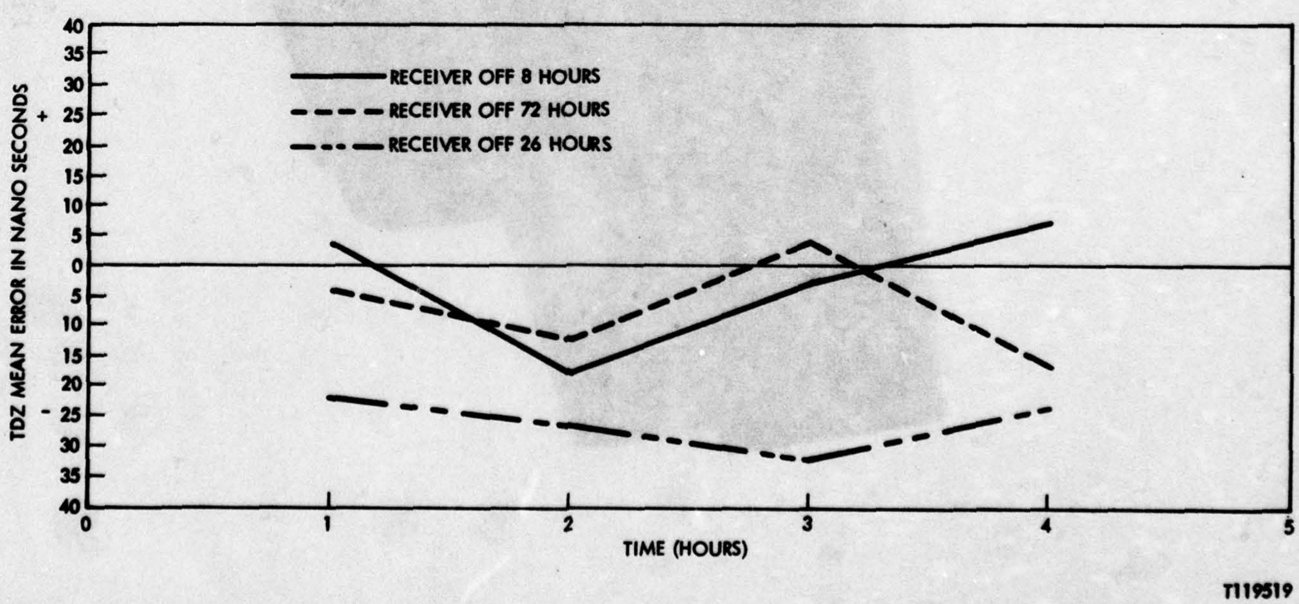


Figure 4-3. Static Accuracy Tests With Original Oscillator

SECTION 5

GRAPHICS IMPROVEMENTS

INTRODUCTION

The three major problems with the St. Marys LPGS system's graphics were the amount of computer processing time required to generate a map-update; the lack of a current map display while the map update is being computed; and the clutter on the display. The St. Marys graphics software has been modified to correct or reduce these problems. The design criteria used were:

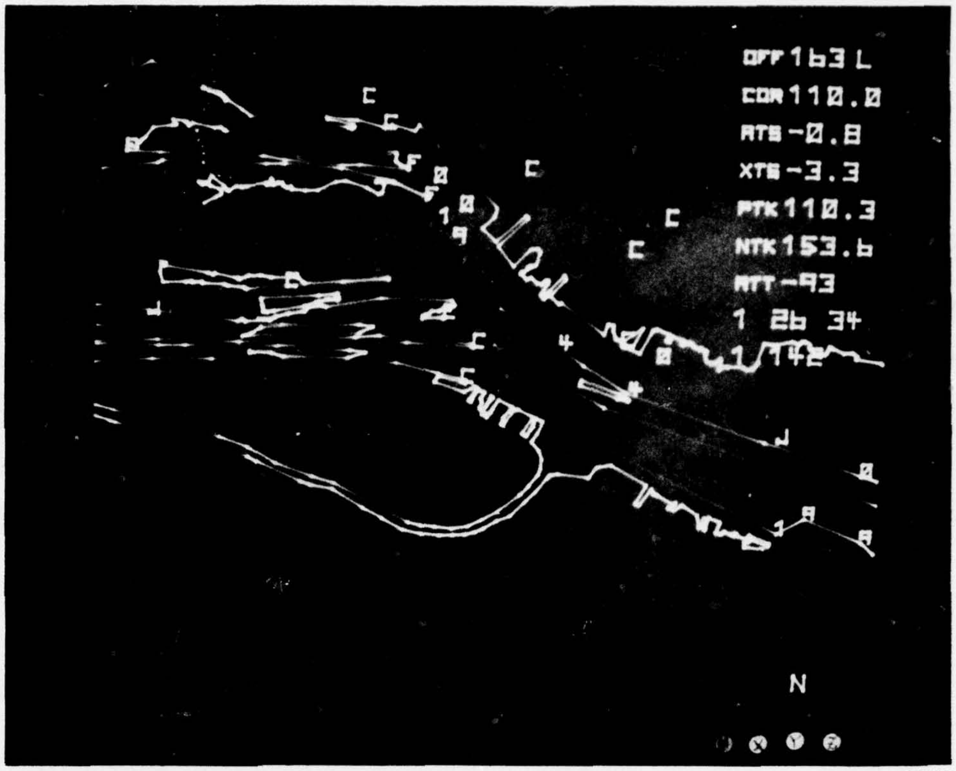
1. Reduce clutter on display.
2. Minimize the interval between Kalman updates.
3. Minimize the time between initiation and completion of map update.

The second two criteria are somewhat conflicting; During map updates, the interval between Kalman updates can be minimized only at the expense of a longer time between initiation and completion of the map update, and conversely, one method of shortening the time between initiation and completion of map updates is to lengthen the interval between Kalman updates. Since system accuracy is a function of the Kalman rate, and we were more interested in improving accuracy than graphics performance, we have avoided making any graphics improvements which would slow the Kalman update rate.

5.1 REDUCE CLUTTER

The clutter on the display was reduced by leaving a strip on the side of the screen for the alphanumeric data. Figure 5-1 shows display before modification and Figure 5-2 shows display with modification. This was accomplished by changing the gain on the display so that full horizontal (X) scale was 12 inches instead of 10 inches. (The transformation $X' = \frac{6}{5} X$ was applied to the screen.) The equation

```
XX = XX* 5./6.
```



P107173

Figure 5-1. Graphics Display Unmodified
(Scale Factor 4 Inches/Mile)

P118929

Figure 5-2. Graphics Display (Modified)

was implemented in PLOT to compensate for this transformation. The X-coordinates in the calling sequence to NOTE in GLABL and GBSTA were transformed by

$$XX = (XX + 2.) * 5./6.$$

These two changes resulted in the map appearing as before in a 10" x 10" square and the alphanumeric data appearing in a 10" x 2" strip to the right of the map.

5.2 REDUCE COMPUTER PROCESSING TIME

The original graphics implementation requires that the data file for the entire St. Marys River be searched by the computer for each map update, even though only a small fraction (typically less than 5%) of this data is displayed on the CRT screen. This implementation is grossly wasteful of computer time, and requires in excess of one minute to complete the file searching and the redrawing of the new display. The original contract requirements called for increasing the map update speed by deleting the searching of the entire data file. It was felt that this could be accomplished by segmenting the river data and searching only those segments that were in proximity to the ship.

After investigation, it was decided that the proposed segmenting was too complex and high-risk to complete within the remaining time frame for the contract. An alternate approach to improving graphics redraw speed, suggested by Teledyne, involved two modifications. The amount of data stored on each disk sector was doubled, and the original graphics code was optimized. Before modification each disk sector contained 32 latitude or longitude numbers. As each sector is capable of containing 64 such numbers the software was changed to take advantage of this fact. The map data common area (IBUFR) was enlarged to 324 words in all programs which reference COMMON storage. The vectors IBUF1, IBUF2, IBUF3, TLLAT, TLLON, PTLAT, PTLON, PTYPE were all doubled in size, and the relevant equivalence statements were modified accordingly in GMAPU, GINIT, GISØ1, GISØ3 and GISØ8. The DO loop parameters associated with the processing of these vectors have also been doubled.

The FORTRAN code for GMAPU was optimized in the following manner. Whenever possible logical IF's were changed to arithmetic IF's. Subroutine calls were eliminated. Subroutines were optimized (NOTE), and constants were computed outside loops, (CSIZE).

5.3 ADDITIONAL MODIFICATIONS

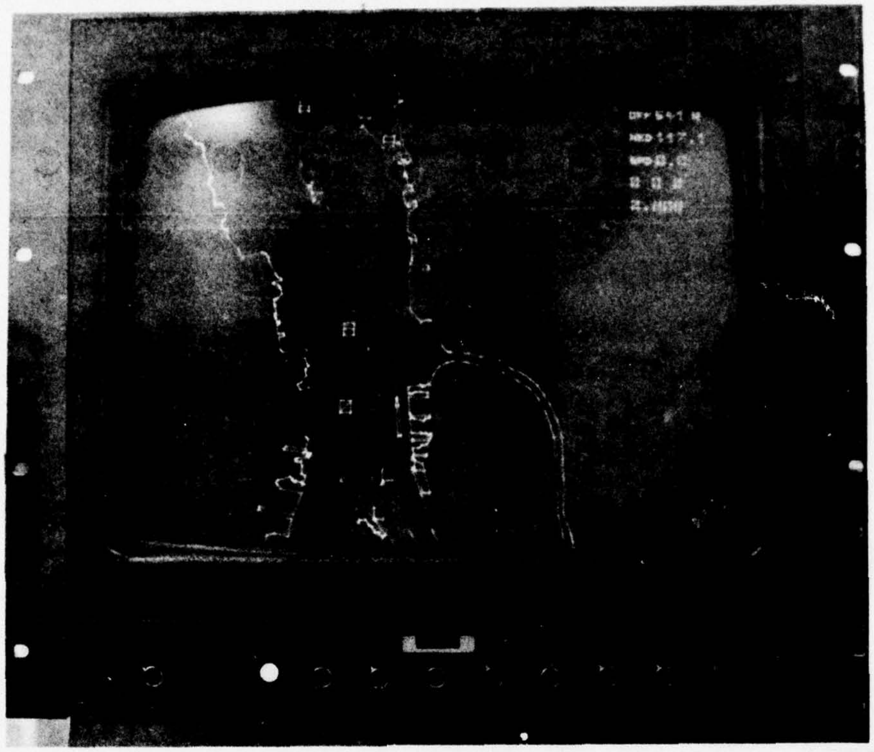
The following modifications were also made to the St. Marys System:

1. Non-relevant software was removed. (Six programs that were not being used have been removed. They are AXIS, DEGIN, DPR2X, SPCRT, WRITC.
2. When in the TRACK-UP mode the vessel symbol will now start at the bottom center of the screen each time the display pages. See Figure 5-3.

5.4 DEGREE OF IMPROVEMENT

The degree of improvement obtained by these modifications can be determined by observing the system in operation. The clutter on the screen has been reduced. No further reduction in clutter can be obtained with the present graphics interface. The improvements resulted in an 11% reduction in processing time.

The modified software subroutines are contained in Volume II.



P11892

Figure 5-3. TRACK-UP Display

SECTION 6

SYSTEM PERFORMANCE IMPROVEMENTS

Two hardware modifications were implemented into the system to improve the performance of the system. One modification improves the initialization procedure and performance by controlling the LORAN receiver status input. The other modification consisted of adding more filter capacitors on the LORAN/Gyro interface board to improve performance by decreasing noise which intermittently caused invalid LORAN status data to be generated.

6.1 LORAN RECEIVER STATUS MODIFICATION

When initializing the original system, the TDL-708 could not be turned on until system initialization had been completed, otherwise the LORAN/Gyro interface board would occasionally load the incorrect LORAN receiver status (i.e. search, track, or float mode) into its memory. To correct this condition, the receiver power had to be recycled so that the receiver would transition through all the status modes thereby allowing the interface board to load the data correctly.

The LORAN/Gyro interface board contains memory and timing logic for storing the data from the TDL-708 RAMs (Random Access Memory) until the computer is ready to read in the data which is approximately every 200 milliseconds. After the computer reads in the stored data, new data from the TDL-708 is strobed into the memory. The new time difference data is updated every load cycle but status data is not updated again until the receiver changes states.

The structure of the TDL-708 receiver's software is mechanized so that status is updated only when the receiver is transitioning from one state to another until it reaches track state. After acquiring track, the program never addresses or outputs the status again until a transition takes place (i.e., receiver goes to float state (8) or any other state). Therefore, the status data must be captured during the time the receiver is transitioning through the various states. If the

computer is busy during that time, or not operating to accept LORAN data, then the correct state will not be loaded into the interface board. Then, the only way to get the correct status is to turn off the TDL-708 receiver and allow it to recycle through the various states so that the correct data will be loaded into the interface memory.

A modification was made in the LORAN/Gyro interface board S/N02 and the TDL-708 LORAN receiver, SN0112, for the purpose of continually resetting the TDL-708 until the operating program is ready to accept LORAN data. This is accomplished as follows: Refer to Figures 6-1 and 6-2.

A monostable multivibrator (U1) with a time constant of approximately 500 milliseconds and a free running multivibrator (U2) with a time constant of approximately one second were added to the LORAN/GYRO interface board. These multivibrators control the re-initialization of the TDL-708 receiver via the computer. When the computer isn't outputting load pulses, multivibrator U2 is switching. This output is applied to a level shifter in the TDL-708 receiver that re-initializes the receiver approximately every second, thereby preventing the receiver from acquiring track mode until load pulses are present.

The monostable multivibrator (U1) is triggered on the first load pulse from the computer and remains set as long as pulses are present. When pulses are not present U1 will reset within 500 milliseconds, which allows U2 MV to reset the receiver for updating status data.

A buffered level shifter, U3 and U4 was added to the TDL-708 receiver DPU (digital processing unit). This shifter resets the CPU program counter by shifting the voltage from +5V to -12 VDC.

6.2 LORAN/GYRO INTERFACE FILTERING IMPROVEMENT

Additional filtering was incorporated on the LORAN/GYRO interface board, SN 02, to improve noise rejection within the memory area (74C910 ICs). Since the

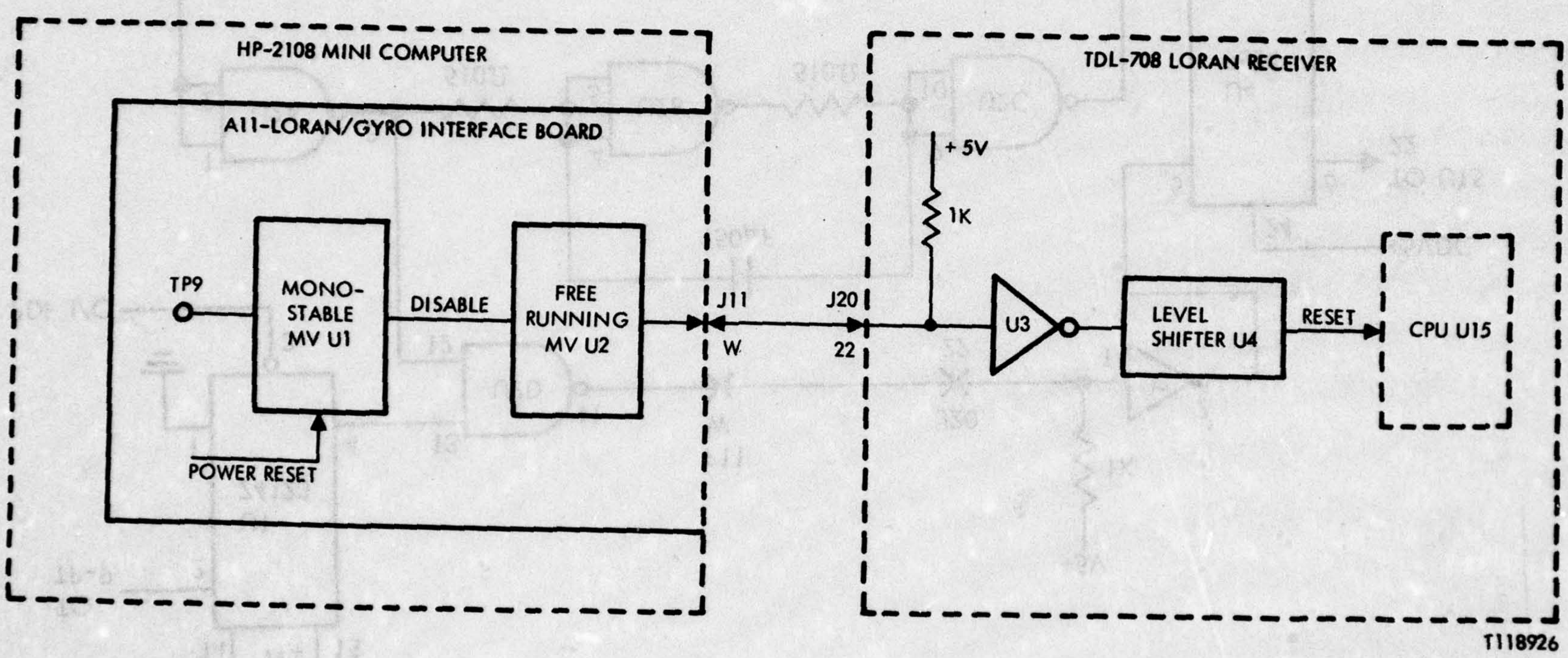


Figure 6-1. Block Diagram of LORAN/Receiver Status Modification

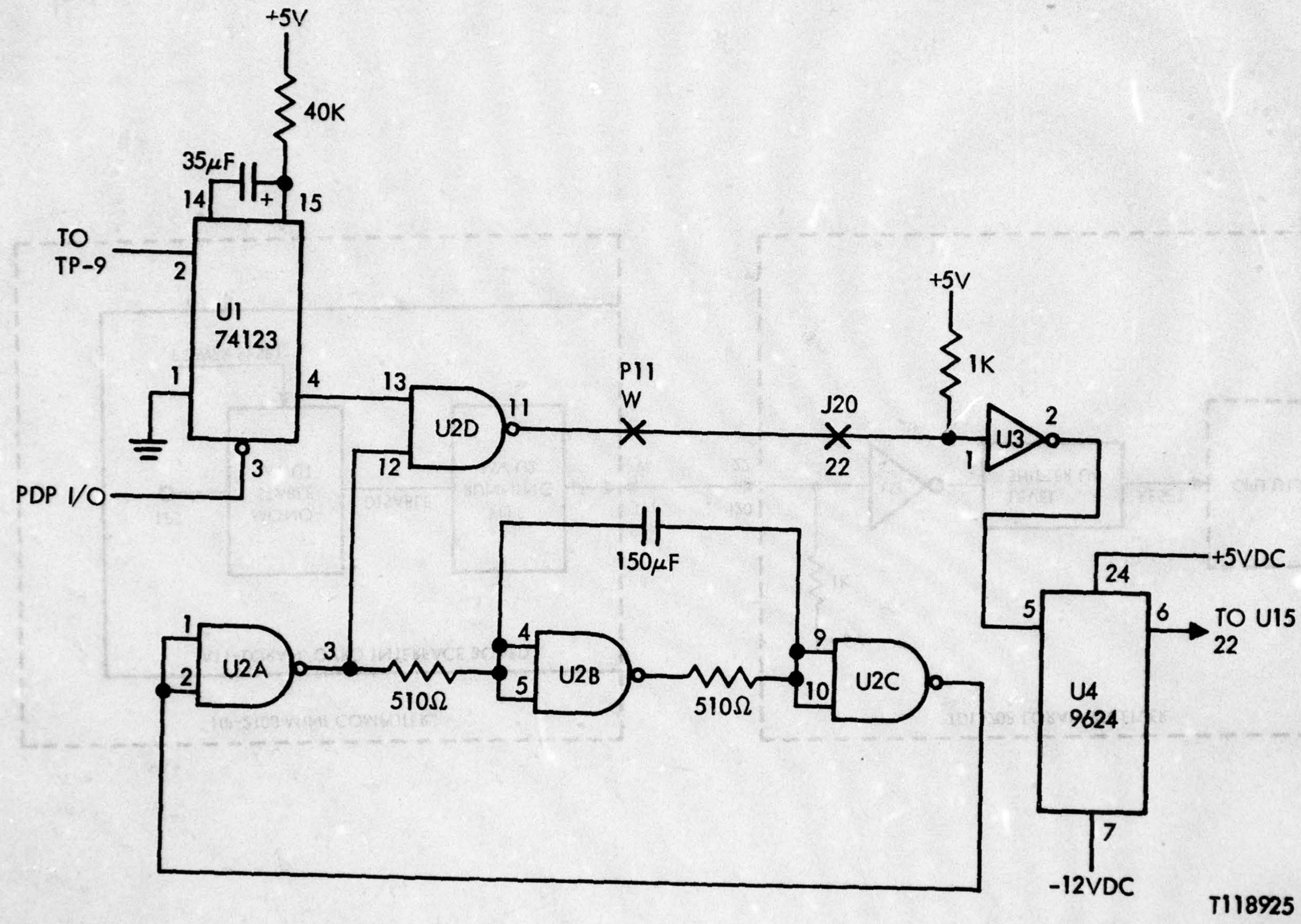


Figure 6-2. LORAN/Receiver Status Modification Circuit

LORAN receiver status data is updated only when the TDL-708 receiver changes state, noise spikes of sufficient amplitude could alter the memory's data if noise rejection isn't high. Two 0.1 ufd capacitors were connected to the 74C910 memory voltage input to filter noise on the +5 VDC line.

6.3 DEGREE OF IMPROVEMENT

The system was tested numerous times for extended periods to evaluate the modification incorporated to improve performance. No LORAN status problems were detected during initialization and operation tests.

SECTION 7

LORAN RECEIVER PHASE TRACKER SIMULATION

To determine if any TDL-708 Loran receiver modifications were required to improve receiver response, a simulation analysis was performed of the receiver tracking loop which is shown schematically in Figure 7-1. Certain parametric studies were performed in an effort to determine a design configuration that minimized the mean square strobe position error under a wide variety of operational conditions. The parameters which were varied were: (1) phase buffer threshold, (2) DBUF register content and (3) DBUF to phase buffer feedback gain. Monte Carlo runs were made for vehicle velocities of 0 and 10 nanosec/GRI and for signal to noise ratios of infinity and 6 dB. The performance measures which were calculated were: ground track and energy track average strobe biases and standard deviations. All numbers were based on a Monte Carlo simulation over 1000 GRI's. All runs were made under both the energy track enabled and disabled condition.

7.1 RUN RESULTS

The results of the runs may be summarized as follows:

1. For an infinite signal to noise ratio and no vehicle velocity, there is no bias in the average strobe position for either ground wave or energy tracking for runs made with the nominal design parameter values.

2. When either vehicle velocity or noise is present, then a strobe error bias as well as an increase in the strobe position standard deviation appears.

3. None of the parameter modifications furnish any uniform improvement in performance over the nominal present design values for the SNR's and vehicle velocities examined. The nominal present design values are:

   ΔBUF = 4
   ΔBUF FEEDBACK = 2
   PHASE BUFFER (PBUF) THRESHOLD = 16

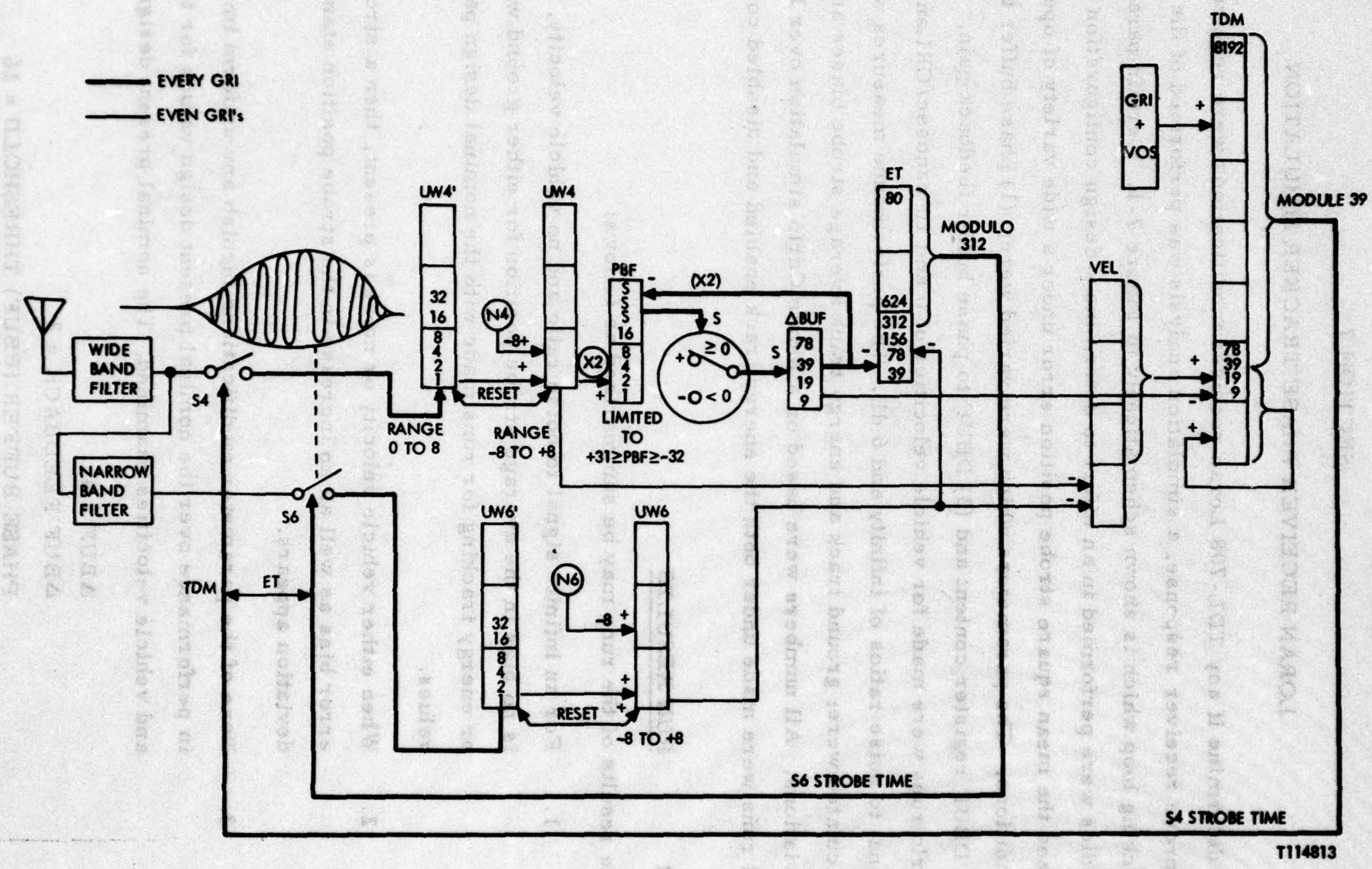


Figure 7-1. State 11 (Track) Master Phase Tracking

4. The simulation results indicate that superior tracking is always achieved when energy tracking is disabled.

7.2 SIMULATION RESULTS

The numerical results of the simulation are shown in Section 7.2.1.

1. List of Abbreviations

ΔBUF	=	Delta Feed Back From Phase Buffer	
E. T.	=	Energy Track	
G. T.	=	Ground Track	
IET	=	Energy track control	1 = Enabled 0 = Disabled
PBUF	=	Phase Buffer Register	
SNR	=	Signal-to-noise ratio	
VEL	=	Velocity	
GRI	=	Group repetition interval (of LORAN pulses)	

7.2.1 Test Results of Simulation

Table 7-1.

With Energy Track

IET = 1
SNR = ∞
VEL = 0
ΔBUF = 4
ΔBUF Feedback = 2

G.T. Bias	G.T. σ	E.T. Bias	E.T. σ	PBUF Threshold
0.0	56.5	78.2	375.5	0
0.0	56.5	78.2	375.5	1
0.0	56.5	78.2	375.5	2
0.0	56.5	78.2	375.5	4
0.0	56.5	78.2	375.5	8
18.9	37.3	7.6	289.0	16

Without Energy Track

IET = 0
SNR = ∞
VEL = 0
ΔBUF = 4
ΔBUF Feedback = 2

G.T. Bias	G.T. σ	PBUF Threshold
0.0	56.5	0
0.0	56.5	1
0.0	56.5	2
0.0	56.5	4
0.0	56.5	8
6.7	50.7	16

NOTE: All biases and σ's are in nanoseconds

Table 7-2.

With Energy Track

IET = 1
SNR = ∞
VEL = 10 nsec/GRI
ΔBUF = 4
ΔBUF Feedback = 2

G. T. Bias	G. T. σ	E. T. Bias	E. T. σ	PBUF Threshold
6.2	55.2	-43.2	311	0
6.2	55.2	-43.2	311	2
6.2	55.2	-43.2	311	4
6.2	55.2	-43.2	311	8
29.0	85.5	55.9	310.2	16

Without Energy Track

IET = 0
SNR = ∞
VEL = 10 nsec/GRI
ΔBUF = 4
ΔBUF Feedback = 2

G. T. Bias	G. T. σ	PBUF Threshold
-4.2	62.4	0
-4.2	62.4	2
-4.2	62.4	4
-4.2	62.4	8
2.0	50.6	16
2.0	50.6	24

Table 7-3.

With Energy Track

IET	=	1
SNR	=	6 dB
VEL	=	0
ΔBUF	=	4
ΔBUF Feedback	=	2

G. T. Bias	G. T. σ	E. T. Bias	E. T. σ	PBUF Threshold
21.2	161.6	-42.0	207	0
35.8	102.9	-37.3	214	1
35.8	162.9	-37.3	214	2
38.4	149.7	-39.1	199.2	4
31.3	73.7	-36.8	179.6	8
6.0	47.3	-40.2	175.8	16
15.3	65.2	-35.3	177.3	24

Without Energy Track

IET	=	0
SNR	=	6 dB
VEL	=	0
ΔBUF	=	4
ΔBUF Feedback	=	2

G. T. Bias	G. T. σ	PBUF Threshold
-4	185.1	0
25.4	175	1
25.4	175	2
8.2	149	4
5.9	102	8
-12.9	262	16

Table 7-4.

With Energy Track

IET = 1
SNR = 6 dB
VEL = 10 nsec/GRI
ΔBUF = 4
ΔBUF Feedback = 2

G. T. Bias	G. T. σ	E. T. Bias	E. T. σ	PBUF Threshold
73.2	175.6	-25.5	216.2	0
97.3	165.8	-24.6	199.2	1
97.3	165.8	-24.6	199.2	2
89.9	155.2	-20.1	201.7	4
89.8	85.0	-22.7	175.3	8
75.4	193.8	-36.5	172.7	16

Without Energy Track

IET = 0
SNR = 6 dB
VEL = 10 nsec/GRI
ΔBUF = 4
ΔBUF Feedback = 2

G. T. Bias	G. T. σ	PBUF Threshold
17.1	169.8	0
25.5	182	1
25.5	182	2
9.2	169.3	4
12.2	104.0	8
13.6	172.4	16
19.3	290.3	24

Table 7-5.

With Energy Track

IET = 1
VEL = 0
SNR = ∞
ΔBUF = 2 *
ΔBUF Feedback = 2

NOTE: (*) indicates the non-nominal values of the parameters which were varied with the exception of the PBUF Threshold.

G. T. Bias	G. T. σ	E. T. Bias	E. T. σ	PBUF Threshold
20	37.4	21.2	435	0
20	37.4	21.2	435	4
10.0	36.1	11.3	424	16
15.5	37.4	16.7	392	24

Without Energy Track

IET = 0
VEL = 0
SNR = ∞
ΔBUF = 2 *
ΔBUF Feedback = 2

G. T. Bias	G. T. σ	PBUF Threshold
-5.2	64.3	0
23.0	81.0	4
15.2	38.8	16
10.5	48.3	24

NOTE: All biases and σ's are in nanoseconds.

Table 7-6.

With Energy Track

IET	=	1
VEL	=	10 nsec/GRI
SNR	=	∞
ΔBUF	=	2 *
ΔBUF Feedback	=	2

G. T. Bias	G. T. σ	E. T. Bias	E. T. σ	PBUF Threshold
30.3	59.7	-104.7	392.6	0
24.5	50.7	- 81.7	394.6	2
24.5	50.9	- 81.7	394.6	4
31.7	50.6	- 99.6	390.3	8
17.4	32.2	-140.1	372.7	16
18.5	29.4	-167.8	364.9	24

Without Energy/Track

IET	=	0
VEL	=	10 nsec/GRI
SNR	=	∞
ΔBUF	=	2 *
ΔBUF Feedback	=	2

G. T. Bias	G. T. σ	PBUF Threshold
15.7	77.7	0
-3.1	77.8	2
-3.1	77.8	4
4.3	58.8	8
2.2	65.7	16
25.0	70.5	24

Table 7-7.

With Energy Track

IET = 1
VEL = 0 nsec/GRI
SNR = 6 dB
ΔBUF = 2 *
ΔBUF Feedback = 2

G. T. Bias	G. T. σ	E. T. Bias	E. T. σ	PBUF Threshold
-10.4	95.1	-29.8	184.4	0
73.6	75.3	-36.4	176.6	2
61.2	63.5	-53.1	187.3	4
55.8	44.6	-38.6	171.6	8
-51.9	48.6	-41.3	174.1	16
-57.1	39.8	-39.6	171.5	24

Without Energy Track

IET = 0
VEL = 0 nsec/GRI
SNR = 6 dB
ΔBUF = 2 *
ΔBUF Feedback = 2

G. T. Bias	G. T. σ	PBUF Threshold
13.7	114.4	0
15.6	87.5	2
10.6	70.9	4
-1.3	116.3	8
-17.1	294.7	16
-16.2	320.7	24

Table 7-8.

With Energy Track

IET = 1
VEL = 10 nsec/GRI
SNR = 6 dB
ΔBUF = 2 *
ΔBUF Feedback = 2

G. T. Bias	G. T. σ	E. T. Bias	E. T. σ	PBUF Threshold
168.4	85.9	-41.6	200.2	0
210.9	85.6	-46.6	202.7	2
252.0	68.9	-45.5	194.2	4
349.2	83.4	-38.9	214.1	8
471.3	125.1	-45.0	207.9	16
545.0	139.1	-40.0	216.1	24

Without Energy Track

IET = 0
VEL = 10 nsec/GRI
SNR = 6 dB
ΔBUF = 2 *
ΔBUF Feedback = 2

G. T. Bias	G. T. σ	PBUF Threshold
22.2	112.3	0
12.7	100.8	2
13.0	80.8	4
14.6	102.6	8
19.3	190.3	16
19.3	190.3	24

Table 7-9.

With Energy Track

IET	=	1
VEL	=	0
SNR	=	∞
ΔBUF	=	4
ΔBUF Feedback	=	1 *

G. T. Bias	G. T. σ	E. T. Bias	E. T. σ	PBUF Threshold
0	56.5	78.2	375.5	0
0	56.5	78.2	375.5	2
0	56.5	78.2	375.5	4
-5.3	60.0	-31.5	228.7	8
-1.2	74.9	17.0	278.6	16

Without Energy Track

IET	=	0
VEL	=	0
SNR	=	∞
ΔBUF	=	4
ΔBUF Feedback	=	1 *

G. T. Bias	G. T. σ	PBUF Threshold
0.0	56.5	0
0.0	56.5	2
0.0	56.5	4
1.6	67.8	8
13.2	94.1	16

NOTE: All biases and σ's are in nanoseconds.

Table 7-10.

With Energy Track

IET	=	1
VEL	=	10 nsec/GRI
SNR	=	∞
ΔBUF	=	4
ΔBUF Feedback	=	1 *

G. T. Bias	G. T. σ	E. T. Bias	E. T. σ	PBUF Threshold
4.1	84.6	-3.4	320.9	0
1.6	91.9	-10.2	321.1	2
1.6	91.9	-10.2	321.1	4
5.2	80.5	-8.0	306.4	8
3.7	67.6	-5.1	322.4	16
0.2	66.2	0.2	308.5	24

Without Energy Track

IET	=	0
VEL	=	10 nsec/GRI
SNR	=	∞
ΔBUF	=	4
ΔBUF Feedback	=	1 *

G. T. Bias	G. T. σ	PBUF Threshold
-3.5	99.2	0
-0.6	90.9	2
-0.6	90.9	4
-0.4	88.1	8
1.8	78.3	16

Table 7-11.

With Energy Track

IET = 1
VEL = 0 nsec/GRI
SNR = 6 dB
ΔBUF = 4
ΔBUF Feedback = 1 *

G. T. Bias	G. T. σ	E. T. Bias	E. T. σ	PBUF Threshold
12.8	130.6	-36.5	192.6	0
32.1	115.8	-27.4	186.4	2
25.6	100.2	-36.2	186.0	4
16.5	90.8	-42.9	186.1	8
10.6	131.5	-46.9	191.8	16
9.2	137.2	-47.7	191.1	24

Without Energy Track

IET = 0
VEL = 0 nsec/GRI
SNR = 6 dB
ΔBUF = 4
ΔBUF Feedback = 1 *

G. T. Bias	G. T. σ	PBUF Threshold
3.4	134.9	0
12.9	131.9	2
8.7	104.9	4
10.1	95.3	8
-9.2	287.2	16
-19.8	307.4	24

Table 7-12.

With Energy Track

IET = 1
VEL = 10 nsec/GRI
SNR = 6 dB
ΔBUF = 4
ΔBUF Feedback = 1 *

G. T. Bias	G. T. σ	E. T. Bias	E. T. σ	PBUF Threshold
35.3	134.6	-39.7	193.8	0
52.7	131.2	-23.5	194.2	2
53.4	101.5	-28.5	185.4	4
52.8	105.3	-25.4	183.4	8
46.1	149.6	-31.4	180.8	16
41.7	232.1	-32.7	186.0	24

Without Energy Track

IET = 0
VEL = 10 nsec/GRI
SNR = 6 dB
ΔBUF = 4
ΔBUF Feedback = 1 *

G. T. Bias	G. T. σ	PBUF Threshold
23.0	142.2	0
22.3	139.7	2
24.9	103.0	4
22.2	110.5	8
19.3	190.3	16
19.3	190.3	24

SECTION 8

SYSTEM TEMPERATURE TEST

INTRODUCTION

While operating the LPGS system on the ore carrier Arthur M. Anderson, an apparent heat related problem intermittently caused the computer to hang-up. The system seemed to operate properly after removing the side panels on the equipment cabinet which houses the Hewlett Packard minicomputer, Sykes floppy disk unit, and Megatek graphics interface unit. Since the equipment cabinet was located in the bridge next to large windows, the ambient temperature probably exceeded +90°F during hot days. However, the equipment is designed to operate up to 100°F. Table 8-1 lists the temperature range of each equipment per specification.

Table 8-1.

Subsystem	Temperature Range	
	Operate	Non-Operate
HP-2108 Computer	+32° to +131°F	-40° to +167°F
Sykes Floppy Disk	+50° to +100°F	-30° to +150°F
Megatek Graphics	+32° to +122°F	-40° to +158°F
HP-2644 Terminal	+40° to +104°F	+14° to +149°F
HP-1317 Graphics Display	+32° to +131°F	-40° to +158°F
TDL-708 Loran Receiver	-4° to 140°F	-40° to 167°F

As part of the Improvements Contract, Teledyne was tasked to determine if a hardware or cooling design problem existed.

8.1 TEMPERATURE TESTS

To verify the heat problem, the system, with the exception of the HP-2644 and HP-1317 units, was set up in an environmental chamber for temperature testing. Thirteen

temperature probes were attached at various places on each unit and in the cabinet for recording temperature.

The system was initialized, and the chamber temperature was set for +100°F. When the chamber temperature reached approximately +85°F, the HP-2108 computer halted. This verified the problem that had occurred in the field. To isolate the problem area, the computer was replaced with the spare computer and the test was resumed, but the system still wouldn't initialize. The problem appeared to be in the Sykes unit, so it was exchanged with the spare disk drive; then the system initialized properly.

Chamber temperature stabilized at +105°F within 30 minutes, and the system operated at this temperature for two hours without any problems. Chamber temperature was then increased to +120°F and operated for another two hours without any problems.

Table 8-2 lists the temperatures recorded at various areas.

Table 8-2.

Temperature Probe Location	Recorded Temperature
- Chamber	+121°F
- Under door of Sykes top drive unit	+129°F
- Rear of Sykes unit near power supply	+129°F
- Right side of computer (exhaust)	+128°F
- Left side of computer (intake)	+123°F
- Computer I/O section	+124°F
- Top of Megatek Graphics Unit	+123°F
- Top of equipment cabinet	+122°F

8.2 TEST RESULTS

The temperature testing verified that a hardware problem existed rather than a cooling problem. The hardware problem in the computer was isolated to a heat sensitive module - Fast-Fortran processor module #1 - but the problem encountered with the Sykes floppy disk unit could not be duplicated.

The heat sensitive Fast FORTRAN processor module #1 was replaced with a new module and the computer was retested in the environmental chamber for two hours at a temperature of +120°F without any problems.

SECTION 9

RECOMMENDED FURTHER IMPROVEMENTS

Following are several recommended improvements to consider in the future that will improve the system performance and graphics display:

a. Substitute Graphics Interface Unit - Using a different state-of-the-art interface unit (HP-1350A) would allow all the display lines to be drawn with equal intensity, tremendously improving the readability of the display on the 17 inch CRT screen.

   This newer unit has the capability of driving additional displays, and permits the selection of different information on each screen. For instance, a small display could be located near the ship's helmsman to display only alphanumeric navigational data such as speed, off-track distance, course, and time to turn at waypoint. Another large display could be located near the navigator for displaying selected channel information. This improvement requires both hardware and extensive software changes.

b. Maximize the Look-Ahead Area - This software change would prevent a graphics redraw during a turn, when the ship's symbol is within 15% of the screen's edge. Also it would give the captain more warning on upcoming turns.

c. Implement a Comment Command - This software change would allow the operator to enter comments on the system printer output.

d. Clean-up the COMMON Structure - This will make the program easier to read and to modify.

e. Don't blank the display when paging - This would ensure that an illustration of the channel is always displayed on the screen.

f. Reset Loran Receiver when invalid Loran status is detected - Section 6.1 described a modification implemented to help solve the problem of incorrect status being transferred from the Loran-C receiver to the computer. That modification provides only "band-aid" relief; The status problem should ultimately be corrected either by modifying the software within the TDL-708 Loran-C Receiver to accommodate the needs of the computer interface, or by functionally redesigning the interface itself. Both of these alternatives require extensive effort.

If it appears that the Section 6.1 modification is insufficient as a temporary "fix", then additional help might be obtained by modifying the LPGS software to force a recycling of the receiver whenever the receiver appears to have lost track of a station. Figure 9-1 shows the flow diagram of the recommended software changes.

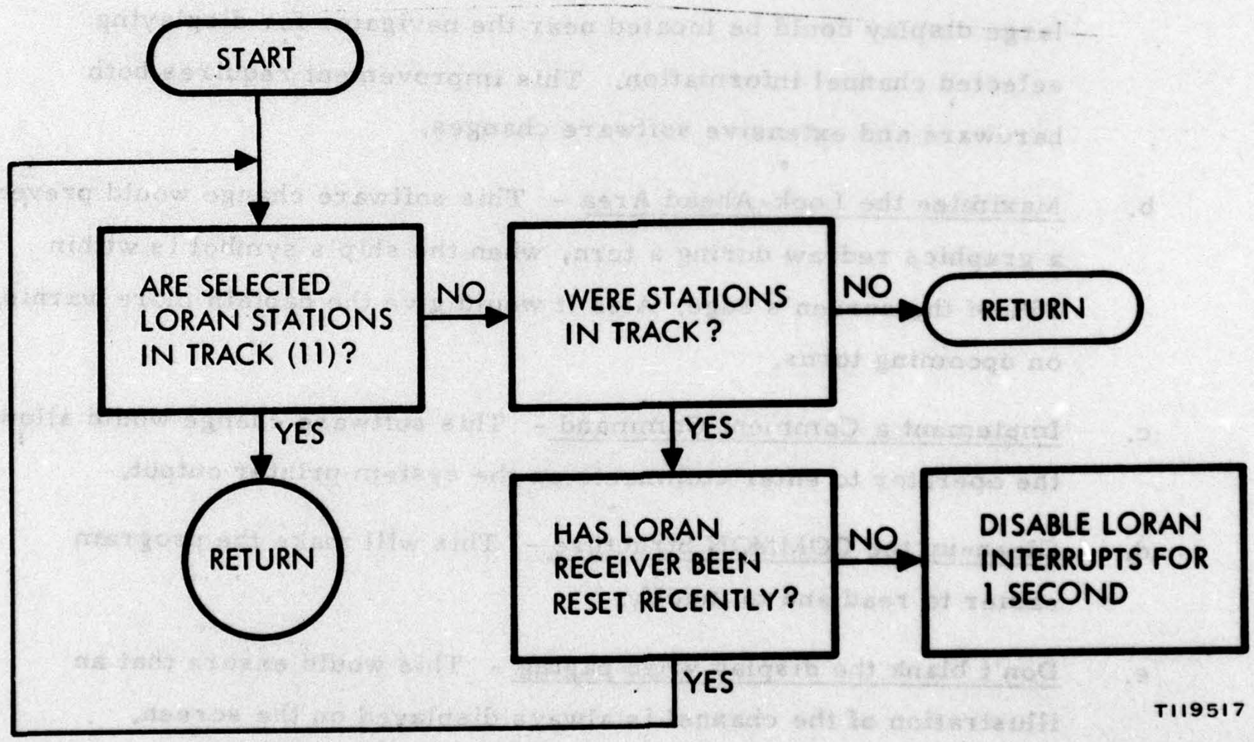


Figure 9-1. Flow Diagram for Loran Status Reset

62

REFERENCE

1. Olsen, D. L. - "LORAN-C USER EQUIPMENT ON A GREAT LAKES ORE CARRIER".

   Paper presented at the 1978 Assembly Meeting of the Radio Technical Commission for Marine Services in Detroit, Michigan and Windsor, Ontario, April 17-20, 1978.